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Ultrasonic Sickness

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ULTRASONIC SICKNESS or supersonic sickness, as the condition is sometimes called, refers to a series of indefinite symptoms and clinical findings, the cause of which has been attributed to exposure to noise frequencies of the ultrasonic ranges. Various temporary disturbances in human beings and a variety of harmful and lethal effects upon lower forms of life have been attributed to noise spectra produced by ultrasonic sirens and other similar types of laboratory research equipment. Similar effects also have been produced by exposures to jet engines operated under special laboratory circumstances. However, current interest in ultrasonic sickness has resulted primarily from speculation and observations concerning exposure to jet noise under more ordinary industrial and aeronautical conditions.

The advent of the jet method of travel has given rise to questions concerning the end results in terms of benefit and harm to the fliers. Similar interest has been expressed in others exposed to jet noise.

Supersonic speed and the related ultrasonic noise bring together a rate of travel not heretofore experienced by man and exposures to noise which have been experienced to some extent but not under circumstances similar to those brought about by flight or commonly encountered in aircraft manufacturing activities. The general attitude concerning these two types of associations is made up to a considerable extent of awe of such great speed plus fear of some of the spectacular effects which have been produced on lower forms of life by ultrasonic noise in the laboratory.

Following an unsuccessful attempt by a British test pilot to exceed the speed of sound in a jet plane, there were numerous speculations concerning the physical and physiological possibilities of attaining such a speed. Failure of the airplane was attributed by some to mechanical impossibility to withstand the necessary stresses. Others felt that perhaps the pilot lost his life because it is not physically or physiologically possible for man to penetrate that "invisible curtain" separating sonic and supersonic speeds. These theories subsequently have been disproved by the successful attainment of supersonic speed by both man and the jet propelled plane.

Opinions still are divided, however, concerning the influences of such speed and the related noise exposures upon man. The present-day attitudes on the question fall into one of two broad groups: First, there is the opinion that aside from acoustical damage which may be caused by the sonic frequencies, there is no basis for expecting physical, physiological, or neurological disturbances. The opposing opinion is that in view of the harmful effects which have been produced by ultrasonic noise under experimental conditions, and the subjective symptoms which have been related by some individuals exposed to jet engine noise, the problem is serious.

The conservative attitude which is being taken by many individuals lies between

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these two extremes. The matter is being studied with an open mind, and fragmentary reports of some of the earlier research efforts already are suggesting that these widely opposite points of view soon will be resolved into a common understanding which will be further supported by factual research and practicable exposure experiences.

The subject is being studied comprehensively by the army, the navy, and several universities in the United States. Foreign investigations also are in progress, notably those being carried out under the auspices of the British Air Ministry. Not enough progress has been made to permit formal release of definite conclusions or very many positive findings to date. Some helpful information has been released, however, principally in the form of general discussions and personal communications. These bits of information are drawn upon in this discussion in an attempt to summarize the progress which has been made.

Conclusive studies of the effects of ultrasonic noise upon individuals, and the correct appraisal of the amount of damage a given individual might be found to have suffered are beset with some fundamental shortcomings which have not as yet been worked out in an entirely satisfactory manner. A few of them are worthy of mention here.

First, there is the relatively minor question of terminology. The words "supersonic" and "ultrasonic" often are used interchangeably to refer to the auditory ability to detect sound. The American Standards Association terms "infra-audible," "audible," and "ultra-audible" often are not used at all in this connection. There does seem to be some tendency to use the word "supersonic" in describing the speed of travel and "ultrasonic" in referring to the ranges of hearing. Thus, the term "ultrasonic sickness" is replacing "supersonic sickness."

The defined audible range varies somewhat depending upon whether reference is being made to the ordinarily useful or to the absolute ranges of hearing. The useful ranges usually given are 200 to 18,000 c.p.s.

It is generally believed that the ultrasonic frequencies are more detrimental to hearing at given intensities than are the audible or infra-audible, but the relative influence of these frequencies in association with varying intensities still is not completely clear. Then there is the practicable problem of evaluating hearing loss in individual cases which is due to noise over and above that due to age and disease. Such problems, particularly those related to auditory responses, are of basic importance and must be more clearly defined before they can be put to their greatest possible use in the evaluation of the effects of frequency ranges over and above, or independently of, acoustical damage. Perhaps some or all of these questions may not be answered satisfactorily before practicable exposure experience reveals the true end results of ultrasonic exposures. Such has been the case with other disorders, notably some of the communicable diseases, where epidemiological or mass reaction experience revealed the mode of spread and suggested preventive measures long before the true etiological causes were scientifically determined.

The principal components of the noise spectrum around which this entire question of ultrasonic sickness centers are intensity and frequency. The findings concerning the importance of these components are falling into a pattern which permits reliable comparisons to be made of their magnitude as produced by jet engines with that of intensities and frequencies produced under similar conditions by conventional piston-type aircraft engines.

Intensity

NOISE EXPOSURE of test operators in control rooms with jet engines operating at various speeds have been found to be in the same general range as those testing piston-type engines under similar circumstances.

Intensities may range upward to 110 decibels, or possibly somewhat higher, at the control panels, depending upon speed at which the engine is being operated, tightness of doors leading to the engine chamber, etc.

During tie-down test runs in the open, intensities may definitely exceed levels of comfort without ear protection. Ranges in excess of 140 decibels, or definitely beyond the scale on the general radio sound level meter, have been noted.

Intensities in the cockpit of jet-propelled craft in flight have been found to range upward to 110 decibels, which is not appreciably higher than that resulting from planes driven by piston-type engines. The intensity of noise at positions in jet planes to the rear of the cockpits might be expected to be somewhat higher because the fields of highest intensity are distal to the jet outlet.

From the standpoint of intensity alone, it is obvious that noise from jet engines and jet-propelled aircraft presents an important potential problem, although it is not essentially unlike that produced by piston-type engines. The incidence and degree of temporary and permanent hearing loss has not yet been determined, but it would seem that, with the governing factors, engine speed, length of exposure, soundproofing, and acoustical protection of individuals being constant, they would be at least in the same order as those resulting from exposure to noise from reciprocating engines.

Frequency

The frequency ranges produced by jet engines are governed by several factors including revolutions per minute and design of the rotor mechanism (number of blades, design of the turbine, etc.). The frequency range may extend all the way from the infra-audible through audible to the ultra-audible ranges. In analyzing noise during flight of jet planes, it was found that the noise contained a higher proportion of middle frequencies (500—2,000 c.p.s.) than does the noise from the reciprocating engines. There was a tendency for the peak to move toward the higher frequencies with increasing speed, with the peak of the spectrum being reached at 5,500 c.p.s. during the highest speed. The maximum frequency range was not determined during these studies for the reason that the General Radio Sound Analyzer used does not operate at frequencies greater than 7,500 c.p.s. It is a well known fact that the range of the frequency spectrum may exceed the upper limits of hearing. Since high frequency noise is more likely to impair hearing than low frequency noise of the same intensity, then the question of hearing loss from jet engines assumes greater theoretical importance than that resulting from reciprocating engines.

The problem of the higher frequencies is definitely associated with their penetrability. The standard flying helmet affords sufficient protection against the higher frequencies to make it unlikely that the jet engine noise presents a greater hearing problem to pilots provided the helmets are worn.

Sound analyses in control rooms during the operation of jet engines at various speeds have shown the frequencies to range from 30 to 120 c.p.s. It would seem that, under such test conditions, the soundproofing materials adequately screen out the higher frequencies. Operators stationed in control rooms still may experience intensities in varying ranges, but the problem is essentially of the same degree of importance as intensity of noise generated by piston-type engines.

Individuals exposed to noise during ground test operations usually are not protected as well as those stationed in test cell control rooms. Heavy clothing and helmets have been used to some extent, as well as sponge rubber foot pads.

It is logical to presume that, in view of the low penetrability, the higher frequencies were screened out to an appreciable extent.

Experiments have been made in the vicinity of jet planes in operation at tie-down stations by placing men at various positions in the noisy zone at the rear and sides of the planes. Although some temporary effects were experienced such as hearing loss, fatigue, dizziness, unsteadiness of gait, etc., they cleared up soon after exposure. These tests were made with one type of engine and were too elementary to justify positive predictions concerning harmlessness of such exposures. However, they are in agreement with some of the other scientific observations and opinions on the subject.

In one group of one hundred Royal Air Force pilots and fitters which had been closely followed for a period of six months at the time the findings were reported, the principal complaints included deafness together with tinnitus, tinnitus alone, unpleasant sensations in the ears during running up of the engines, giddiness during running up, discomfort from noise, and weakness. Audiometric, electroencephal-

ographic, and other examinations revealed nothing of significance.

Five other men with 12 to 14 months of exposure to noise from ram-jet combustion engines, for periods up to ten minutes four or five times daily, complained of lassitude, tinnitus, deafness, feeling of unsteadiness, lack of concentration, and reduced ability to see and memorize gauge readings properly.

The noise frequency and intensity levels of exposure were not given for either of these two groups, but for the latter group at least, the intensities were considered to be sufficiently high to require the use of special acoustical protection. Central nervous system, electroencephalographic, and audiometric examinations were negative.

Numerous accounts have been reported in the press of subjective reactions of pilots and workers following exposure to jet engine noise. The symptoms have varied somewhat in type, degree, and duration. They have included headache, dizziness, nausea, unsteadiness of gait, fatigue, temporary hearing loss, tinnitus, altered sensations, and a variety of others, many of which were shown to be due to other causes; none of these represented a clinical entity attributable specifically to exposure to ultrasonic noise. Such symptoms which were actually associated with exposure to noise, and which were investigated adequately, were found to be temporary.

Present-day knowledge of the effects of frequencies indicates that the effects can be grouped into those felt, those heard, and those neither felt nor heard (ultrasonic). Vibrations which are felt may give rise to a feeling of fatigue or to a sensation of dizziness, depending upon the degree of vibration and length of exposure.

Frequencies which are heard may give rise to temporary or permanent hearing loss, depending upon degree and length of exposure. Such noisy exposures may bring on, or intensify, neurotic symptoms, but there is little evidence to the effect that efficiency and output are impaired except from the psychological point of view.

All the effects of ultrasonic frequencies thus far reported describe conditions which also are caused by audible frequencies, and it is the opinion of some authorities that physical and mental discomfort is brought about as a result of their effects upon, or through, the hearing mechanism.

It now appears that, aside from the problem of hearing loss which seems to be of the same basic importance as that caused by reciprocating engines, about all that is left of the ultrasonic sickness problem is psychological although this type of disorder might be quite important. The neurotic symptoms which have been described may be a product of fear of the consequences beyond the threshold of sound, or to the same circumstances which give rise to a certain amount of neurosis among individuals exposed to audible frequencies.

Whether this is truly the case as it now appears to be or whether more significant effects are yet to be discovered must await future developments. In the meantime, industrial health measures should be concerned with the application of existing preventive techniques to the problem as it now is understood. These techniques relate to the control of noise at its point of origin, proper placement, and subsequent acoustical protection of workers.

Control of Noise

THE CONTROL of noise is concerned with aeronautical engineering methods of reducing the noise output and with acoustical engineering methods of masking the noise at its point of elimination. Reduction of noise at its source is a problem which aeronautical engineers are constantly studying. However successful they might become in this direction, it does not appear likely that with the ever increasing demands for energy output and increase in functional efficiency they can be able to reduce the noise to the level of comfortable human tolerance without acoustical and personal protective aids.

Acoustical control measures of the type now provided in modern aircraft engine testing cells afford a degree of protection against jet engine noise equal to that against noise produced by piston-type engines. From the ideal standpoint, this may not always be adequate. Difference of opinion still exists concerning the intensity level above which permanent hearing loss will not be suffered, but a fairly general consensus is that it is 100 decibels. Some will say that this level is 90, or even 80 decibels, while others point to the lack of positive proof that intensities below 115 or 120 decibels cause permanent hearing

loss. Be that as it may, sustained exposure above 100 decibels at least involves a threshold beyond which danger of hearing loss exists.

Soundproofing can be developed to the point where intensities on the outside are of no consequence, but certain practical problems relating to facility of operation and installation costs contraindicate such constructions. It is obvious, therefore, that adequate protection of the exposed individual may necessitate the use of personal protective devices.

Properly designed and fitted ear defenders afford degrees of additional protection adequate to finally reduce intensities of noise at the eardrums to safe levels. Numerous types of defenders have been devised. The insert types have attenuating effects which range upward to 45 decibels, but under usual circumstances the amount of reduction is more likely to be in the range of 20 to 25 decibels.

The fit-over, or ear muff types, such as the Mallock-Armstrong Nosonic Ear Defender, afford greater protection, but the problem of maintenance and satisfactory usage also are greater than with the insert types.

The noise in cockpits of military types of jet aircraft usually does not present a problem beyond control by the flying helmet. In addition to reducing intensity, the helmets screen out the higher frequencies.

The control of noise during open air tie-down test operations centers almost entirely around personal protection of the exposed individuals. Ordinary ear plugs hardly can be expected to do the job adequately. Some preliminary experiments with the fit-over and insert types used together indicate that noise intensities at the eardrum can be attenuated to the extent of 40 to 45 decibels.

Such protection should be adequate in all except the most unusual degrees of exposure. The use of resilient foot pads and thick clothing afford additional protection. As a further safeguard against the higher intensities, exposures should be interrupted after an hour or two, and following shorter periods under severe exposure conditions, with equal or longer intervals of non-exposure. Such test operations usually are intermittent and of short duration; consequently, they do not present as serious a problem as that which would result from prolonged operations.

Physical Evaluation and Job Placement

PHYSICAL EVALUATION and placement of employees is of major importance in bringing about any satisfactory "job-worker balance." This is particularly true concerning noisy exposures. As was pointed out earlier in this discussion the principal, if not the entire reaction of individuals to noise spectra regardless of their sonic ranges, is reflected in terms of acoustical and emotional responses. Physical evaluation then should be concerned with the evaluation of hearing ability and with general temperamental stability.

Preplacement evaluations of hearing ability involve physical examination and audiometric measurement of hearing acuity. Partial and progressive hearing losses contra-indicate placement on jobs which are likely to be aggravating unless adequate personal protection can be assured. Depending upon the type and extent of impairment, it might even be unwise to take a chance on the assumption that adequate hearing protection will be maintained.

Evaluation of temperamental fitness is less tangible but no less important in the long run than measurement of hearing acuity. In the average noisy environment, the psychoneurotic consequences of malplacement in terms of absenteeism, substandard efficiency, physical complaints, and labor turnover far outweigh those due to acoustical trauma.

Whether the evaluation of temperamental capacity is made by a psychiatrist or by a job-wise plant physician does not constitute as great a point of importance as does the ability to appreciate how a given type of individual is prone to react to a given type of job. This know-how may be acquired through special training or through clinical and statistical observation.

Job Follow-up

FOLLOW-UP evaluation and observation of worker performance involves audiometric measurements of hearing acuity at intervals, preferably of six months or even shorter periods under some circumstances, and the correlation of these findings with sound analyses made during the same period of time. Any losses of hearing noted

may be due to nonindustrial circumstances such as age and disease, or to exposure to noise. It is not always easy to make this distinction; consequently, it is very helpful to have audiometric findings on a similar but nonexposed or control group.

Clinical and psychiatric follow-up includes periodic examinations and appraisal of the general responses of the individual to his environment. Regardless of how accurately the initial matching of the man with his job might be, minor or major conflicts of one type or another are constantly coming up. Early attention to such variations in the job demands or in the functional capacity of the worker makes it simpler to provide for the necessary readjustments than to give attention later after serious disorders have developed. The indicated readjustment measures depend largely upon the type of disturbance. It is necessary to remove some people from noisy exposures. Temporary removal to quieter jobs is often indicated when comfortable exposures cannot be entirely maintained. In the majority of instances, however, control can be satisfactorily restored by making minor readjustments of soundproofing facilities or by improving personal protective equipment and the manner in which it is used.

Summary

ULTRASONIC sickness as described thus far is an indistinct clinical entity represented by vague subjective symptoms such as headache, nausea, dizziness, disturbances of equilibrium, fatigue, etc., none of which is pathognomonic of any specific physiological, physical, or neurological changes. These symptoms all appear to be temporary and are primarily of neurotic origin. They may or may not be accompanied by hearing loss, but in either case, they are not related exclusively to ultrasonic noise. The same type of disturbances are experienced by individuals exposed to sonic noise.

Exposures of pilots and test-cell operators are in the same ranges as those produced by piston-type engines and the control measures are the same. Tie-down test operations may give rise to intensities in excess of 140 decibels. Control here calls for the use of special types of ear protection and preferably for the limitation of periods of exposure. Thick clothing, helmets, and resilient foot pads also may be of value.

The jet frequencies extend from the infra-audible to the ultra-audible ranges. These extremes have been recorded as 100 to 200,000 c.p.s. but fall off rapidly above 20,000 c.p.s. Test cell operators have been found to be exposed to frequencies of the audible and infra-audible ranges, but soundproofing seems to adequately screen out the higher frequencies. Aviators' helmets also have been found to be adequate in this respect.

The control problems are essentially the same as for sonic noises. They include soundproofing, use of personal protective equipment, and proper functional capacity evaluation and placement of employees. These job placement efforts are primarily concerned with hearing acuity and with temperamental fitness.

Sampling and Determination of Chlorine in Air

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SEVERAL METHODS have been proposed for the detection and determination of chlorine in air. The iodide-thiosulfate method[1] is disadvantageous in that iodine carried over from the first bubbler may not be completely trapped in the second bubbler. In addition, the accuracy is markedly decreased at low concentrations of chlorine—1 ml. of 0.01 normal sodium thiosulfate is the equivalent of 4 parts per million (ppm) for a 30 liter air sample (and some authorities[2] give the value of 0.35 ppm of chlorine as a maximum concentration allowable for prolonged exposure).

Another method[3] proposed is passing the air through two bubblers containing sodium hydroxide with arsenic trioxide. Here again an accurate titration (or turbidity test) is difficult at low yet toxicologically significant concentrations of chlorine. In addition, it cannot be used where there may be chloride salts in the atmosphere.

A method considered was the use of Fe^{++} salt as the absorbing solution and determining the amount of Fe^{++} remaining unoxidized by use of the phenanthroline method.[4] Fe^{++} will react with chlorine, but from experiments done with ferrous ammonium sulfate (100 ml. containing 1.0 mg. Fe^{++}) both in neutral and acid solutions, it appears that one or even a half liter of air per minute is too rapid a flow for obtaining fairly complete reactions when using fritted glass bubblers.

Additional Methods

TWO ADDITIONAL methods[5] have been suggested using ortho-tolidine—one with water as the absorbing medium, the other with an ortho-tolidine solution itself as the medium.

Two bubblers in series with water were tried at various concentrations of chlorine gas at a sampling rate of 1 liter per minute. The results are shown in Table 1.

TABLE 1
EFFICIENCY OF WATER AS ABSORBING MEDIUM FOR CHLORINE

Run No.	Sampling time (Min.)	Concentration of Chlorine caught (p.p.m.) 1st bubbler	2nd bubbler	Percent relative efficiency of first bubbler
1	17.2	7.5	6.6	53.2
2	7.5	3.0	1.5	66.7
3	11.2	1.05	0.375	73.8

As expected the relative efficiency of the first bubbler was greater with lower concentrations of chlorine. Because the absolute efficiency varies with the gas concentration, the use of water as an absorbing medium will not give accurate results.

The use of an ortho-tolidine solution as the collecting medium—the official British method[6]—has two disadvantages. First, the color development due to chlorine absorbed at the beginning of the run reaches a maximum while chlorine is still being absorbed. Thus the results are low; and the longer the sampling time, the greater the error. Secondly, the results are limited in their accuracy due to the gaps in the standards.

It was decided to see whether a weak sodium hydroxide solution would collect the chlorine to form the hypochlorite, which then could be analyzed for available chlorine. Two bubblers in series were used at a sampling rate of one liter per minute, each run being for 35 minutes. The first bubbler contained 100 ml. of 0.10 N, 0.025 N, and 0.0125 N sodium hydroxide respectively; with the second bubbler containing 0.10 N sodium hydroxide in all three runs.

Results

THE RESULTS showed absolute efficiencies of more than 99.9 per cent in each run with chlorine concentration greater than 150 ppm.

The analysis of chlorine was based upon the standard method[7] used in water analysis. The only difference was the addition of 0.1 ml. (two drops) of 5 N sulfuric acid, after the ortho-tolidine was added to a portion of the collecting medium, to neutralize most of the excess alkalinity.

A further check was made on the first run to see whether any chlorine absorbed in the sodium hydroxide would be liberated during long sampling periods through aeration. One-tenth gram of arsenic trioxide was added to the second bubbler of 0.1 N alkali and its contents were analyzed for chlorides by comparative turbidity tests (using silver nitrate). The results showed less than the equivalent of 0.05 ppm chlorine, while the first bubbler showed a concentration greater than 450 ppm.

Two bubblers in series, each containing 100 ml. of 0.1 N sodium hydroxide, were then used at a sampling rate of 3 liters per minute. The first bubbler still showed an absorbing efficiency greater than 99.9% at concentrations of chlorine as high as 100 ppm.

A further test was made with a midget impinger tube containing 10 ml. of 0.1 N sodium hydroxide at a sampling rate of 2.9 liters per minute (more than 0.1 cu. ft. per minute). The outlet of the impinger tube was connected to the inlet of a fritted glass bubbler. The results for the impinger showed a 99.9% efficiency for chlorine concentrations as high as 50 ppm.

Since it is not easy to detect differences of less than 0.05 to 0.10 ppm. of chlorine by visual comparison tests, a further study was made of stability of the alkali solution of chlorine. Thus samples taken in the field could be determined much more accurately by use of a spectrophotometer. (A wave length of 410 m/u gives maximum absorption for the yellow color of the ortho-tolidine test, but standards equivalent to 0.3 to 10 ppm fell below the 10% transmission point. A wave length of 445 m/u was used, for it gave results in the 10 to 90% transmission range.) (See Fig. 1) Results of the stability tests are given in Table 2.

It is evident that the chlorine absorbed was relatively stable only in the 0.1 N alkali solution, especially in the region of the maximum permissible limit (0.35 to 1.0 ppm.) From data obtained on the stability of household bleach (5% chlorine or 50,000

TABLE 2
STABILITY TESTS OF ALKALINE SOLUTIONS CONTAINING AVAILABLE CHLORINE

Solution Normality	Sample No.	Concentration of Chlorine (p.p.m.) Original Solution	After 2 days setting	After 9 days setting
0.1 N	1	15.0	14.4	13.5
NaOH	2	2.2	—	2.0
	3	0.30	0.30	—
0.025 N	1	17.0	15.5	15.5
NaOH	2	3.0	2.1	1.2
	3	0.75	0.60	0.40
0.0125 N	1	13.5	11.0	10.0
NaOH	2	3.0	2.4	1.0

ppm.), the rates of decomposition in the two weaker alkali solutions in Table 2, seem excessive. For example, a 50% bleach in 0.12 N alkali loses but 2% of its strength in 15 days. Only a slight excess of alkali (0.51 gr. sodium hydroxide per liter or 0.0125 N) is needed to stabilize hypochlorite solution. However, it is quite possible that in view of the low concentrations involved, a slight trace of copper, nickel or other slowly oxidizable material would appreciably affect the percentage loss of chlorine in a very dilute hypochlorite solution. This would explain why the relative stability of the stronger chlorine solutions is greater than the weaker solutions in both the 0.025 N and 0.0125 N alkali.

Summary

VARIOUS METHODS for determining chlorine in the air have been discussed and evaluated.

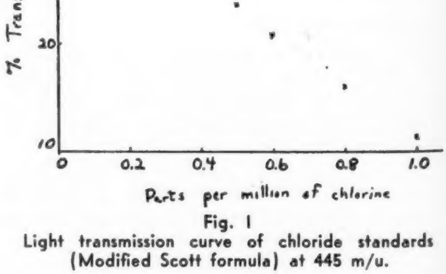

Fig. 1
Light transmission curve of chloride standards (Modified Scott formula) at 445 m/u.

A fritted glass bubbler containing 100 ml. of 0.0125 to 0.10 N sodium hydroxide can be used for collecting chlorine gas, using a slight modification of the standard ortho-tolidine method in water analysis. It is 99.9% efficient for concentrations as great as 150 ppm, at a sampling rate up to 3 liters per minute. With 34.4 liters of sampled air, at 760 mm. mercury pressure and 250° C, the resulting solution will give a direct reading of chlorine in the atmosphere in parts per million.

A midget impinger tube containing 10 ml. of 0.1 N sodium hydroxide at a sampling rate of 0.1 cu. ft. per minute is more than 99.9% efficient for absorbing chlorine from the air in concentrations as high as 50 ppm. With 3.44 liters of sampled air (1 minute, 13 seconds) the resulting solution gives a direct reading of chlorine in the atmosphere in parts per million.

If samples are taken into the laboratory for analysis, 0.10 N alkali should be used to maintain stability of the chlorine absorbed. In addition they should be kept in dark colored bottles until ready for analysis.

Acknowledgment

THE WRITERS wish to express their appreciation to DAVID A. MORTON, JR., for obtaining the data on the transmission curve using the spectrophotometer.

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Note—Dust Concentration in Bolivia's Mines

In table 5 on page 40 of the June 1947 issue of this journal, the method of presentation of data may have led to an erroneous impression that a greatly excessive dust exposure existed in certain of the mines included in the survey. The figures as listed in the paper are the totals of the concentrations of the several samples collected. In order to avoid any ambiguity, this table is reprinted below with the average dust concentrations from all operations except drilling showing for each mine. The final averages are for all individual samples.

TABLE 5
DUST CONCENTRATION FROM ALL OPERATIONS EXCEPT DRILLING

(Millions of particles per cubic foot of air)

Mine	Damp Areas	Dry Areas
A		56 (13)
B	46 (4)*	
C		70 (17)
D	5 (3)	
E	84 (4)	
F	5 (5)	
G	45 (2)	
H		26 (6)
J	40 (2)	
Average: (all samples)	36 (20 samples)	57 (36 samples)

*Figures in parentheses show number of samples

Metal Fume Fever

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THE disease, metal fume fever, is not fully understood and it is not expected that this discussion will result in a complete understanding of it. However, there has been such a common misunderstanding of the true nature of the disease that it appears in order to present such facts as are accepted concerning it.

Metal fume fever is known by a variety of names, as brass chills, zinc chills, foundry ague, foundry shakes and Monday morning fever. These names give a fair idea of the outstanding character of this disease. The disease can be produced experimentally, as we shall have occasion to see a little later. It is a disease which occurs naturally under certain conditions to which workers are exposed, primarily because of the presence of adequate concentrations of the fumes of certain metals and their compounds, especially their oxides. Of these zinc is most important.

A great deal of zinc is handled in the manufacture of brass; thus it is not remarkable that workers in such plants speak of the disease as "brass chills." In earlier days in brass foundries one could find a great many people who had experienced this disease from time to time over the years. In fact, it used to be seen quite frequently. Older workmen could describe the disease in graphic terms.

Expert medical observers have added little from their experiences to the descriptions of the disease as given by the workers themselves. It occurs when the individual is exposed to the fumes of a number of metals: these include zinc—the most important—also manganese, copper, iron, cobalt, cadmium, antimony, lead, and apparently beryllium. Also the disease is produced by exposure to adequate concentrations of magnesium oxide. As might be expected, the disease is associated with the handling of metals as in smelting, foundry work, brazing, welding, burning and cutting operations and in other work of similar nature. It is seen in association with metal trades under conditions in which metals are discharged into the atmosphere as fumes and smoke.

Condensed transcript of an extemporaneous address presented in Nashville on December 5, 1947, at the meeting of the Tennessee Industrial Hygiene Conference.

Disease of Fine Particles

IT IS necessary to differentiate between dust and fumes, for the occurrence of the disease does not coincide with the presence of dust in the atmosphere unless such dust is dispersed in the air as particles of less than one micron in size. Metal fume fever is not a disease of long, but of brief exposure. It may be experienced by a new employee, who is exposed to adequate concentrations on his first day's work. The sick man exhibits none of the characteristics of metal poisoning which we associate with exposure extending over a period of months or years.

Another interesting aspect of the disease is that it is discontinuous in character. The individual is more likely to get the disease on a first exposure than later. He is almost certain not to get the disease on the third, fourth, or fifth day of his exposure. If there is a lapse of time between exposures, the worker is likely to get the disease on the occasion of the first exposure which follows an interval of freedom from exposure. This is where "Monday morning fever" comes in. Following two intervening days from Friday to Monday, which constitute a long weekend, the disease is more likely to occur on Monday than on any one of the succeeding days. Or, this may occur on the first day of work after a holiday or a number of days without exposure.

What is the Clinical Picture

THIS is a disease that can be described better by one who has experienced it than by a physician who has had little opportunity to observe its course. Some four to twelve hours after an adequate exposure, the individual is likely to notice certain symptoms, the first of which may well be an unusual taste in the mouth. This may

be a sweet or metallic taste, or it may be described in some other way so as to suggest that something is wrong with the tasting apparatus. Under such conditions a person who undertakes to smoke a cigarette will have the disagreeable experience that follows from the attempt to smoke during certain other types of illness, notably influenza. Anything taken into the mouth will have a bad taste. The disagreeable taste is described by whatever the individual can think of at the moment as, for example, a metallic taste. There is a dryness and irritation of the throat associated with coughing. There come on rapidly weakness, fatigue, pains in the muscles, pains in the joints, yawning and the feeling as though one is about to come down with an acute illness such as a severe common cold. At this point, the disease looks for all the world and feels for all the world as though it were an infectious process. That is the time in which a differential diagnosis is difficult to make. This is succeeded by the occurrence of chills and fever.

Chills may be of minor type or they may be very severe. The first time I saw a man in this condition he was not nearly so frightened as I was. He knew what it was all about and I did not. I thought he might die. He knew he would not. It was a rather fearful experience. In the case of a severe attack of chills the individual shakes all over and shakes his bed, continuing to do so vigorously for some time. At this particular period, the individual might be thought to be having a severe attack of malaria. The fever may go up to 104°. Usually, however, it is moderate, ranging up to 102°. This goes on for a period which varies with the individual, lasting perhaps for several hours. It is succeeded by a degree of sweating which may be minor or profuse, dependent upon the severity of the illness and the preceeding fever. The individual may sweat enough to drench every article of apparel and bed clothing as well. With the sweating there is a gradual reduction of temperature. After a period of one or two hours, the temperature returns to normal. During this period and before the fever has broken the individual may suffer an attack of nausea and vomiting, which may recur.

Occasionally the chills and sweating may be complicated by convulsions; these do not last very long. Following this series of incidents the individual is likely to have moderate to quite severe pain in the chest, which may vary in severity with the cycle of breathing, but it is commonly described as a more or less continuous feeling of being crushed. The disease runs its course in twenty-four hours or less, leaving something of a "hang over," but no other sequelae. No fatal case has been reported.

The disease tends to recur if the environmental conditions capable of inducing it are not corrected. The workers know what to expect. When symptoms begin to come on they usually do not consult a doctor. Men who have had experience with the disease will not be frightened. There is little more for the doctor to do than they can do for themselves, except to establish the diagnosis with reasonable certainty, and so exclude the need for other therapy. The mistake of assuming that the onset of the general picture is not the beginning of an acute infectious disease may have serious consequences.

The diagnosis, which will be referred to later in detail, is made by careful consideration of the history of the patient, including his occupational history, and by observation of the course of the illness which, manifestly as described, resembles an infectious disease only for a comparatively brief period. The physical signs are chills, fever and sweating, and some hours later signs of moisture at the lung bases and a slight to considerable reduction in the respiratory vital capacity. The only other factor of much significance is the occurrence of a leucocytosis. The white cells in the blood will be increased from the normal level of 6,000 to 8,000 or there abouts, up to 15,000 or even 20,000, some 80 to 85% of which will be neutrophilic. In certain similar diseases a tendency towards an elevation in the leucocyte count will be found, and therefore, this finding has a limited diagnostic value. The leucocytosis comes on with the initial chill and is likely to last for ten to twenty hours after the subsidence of illness.

A very large percentage of these cases have not been treated by a doctor; they get along, generally, without any initial treatment. Let me repeat that the victims do not die and there are no sequelae. Therefore, this is not a seriously disabling di-

sease. These facts make me wonder why it has been classified so regularly as compensable; it rarely lasts long enough to interfere seriously with work. The victim is usually able to return to work on the next day or one day later, and two or three days should be the maximum amount of absence justifiable.

Metallic Poisoning a Potential Complication

THE disease may be complicated by evidence of metallic poisoning. In a situation in which a worker has been exposed repeatedly to high concentrations of metallic fumes it is certain that the fumes will have been breathed. If there have been repeated attacks of metal fume fever then there have been repeated exposures to metallic fumes. For example, in brass foundries we may be dealing with brass castings of high lead content, and under conditions of exposure which give rise, repeatedly, to "brass chills," cases of lead poisoning will be seen from time to time. Evidence of such poisoning may occur in connection with chills.

In situations involving exposure to arsenic, lead, mercury and other toxic metals, individuals who have recovered from chills and fever may be found to have the clinical picture of metallic poisoning. It has occurred that the development of such a clinical picture following a bout of metal fume fever, either immediately thereafter, or after a considerable interval, may be the reason why a doctor was consulted. The doctor may recognize the existence of intoxication after the attack of metal fume fever has passed. There has been a very considerable tendency in the older literature to confuse the issue by relating this situation to metal fume fever. This confusion was responsible for some of the experimental work whereby the differentiation of the two types of disease has been made possible.

Characteristics of Metal Fume Fever

LOOKING at some of the characteristics of the disease we find: (1) The disease is more frequent in exposed males than in exposed females. (2) The disease begins in the first few hours after a day's work, usually on the first day of work following an interval of two or three days with no exposure. (3) It is a disease of inhalation. (4) It cannot be produced by intravenous injection. (5) It is capable of being reproduced in experimental animals. (6) It is a disease associated with the inhalation of particles of very small size. It has been shown in the case of zinc compounds, for example, that the finely divided fume of zinc metal is capable of producing the disease. Respiratory exposure to larger particles of zinc dust will not produce the disease. Thus, metal fume fever is specifically a disease induced by inhalation of finely particulate metallic fumes and oxides—of particles so small that they behave much like a gas and act on the alveolar surfaces of the lung. The effect is exerted on the lung tissues and not on those of the respiratory tract. The particles *must* be of such size as to get into the alveoli. This brings us to the experimental work which put together all the points as made.

Experiments with Zinc Oxide Fumes

DRINKER and his associates,[1,2,3,4] 100 years after the discovery of the disease, made a very extensive study of it and published four papers which present much of our best information on the disease. These investigators were able to show first of all that it is a disease which results from specific metallic fumes. The first paper eliminated much of the concern over the general toxic properties of arsenic, lead and other metallic elements, which complicated the picture. The disease was reproduced by exposure of men for a few hours to known concentrations of zinc fumes on one hand and magnesium oxide on the other. This made it quite clear that a few hours of such exposure were capable of producing the disease. It was shown, when a man was exposed to zinc fumes, with resultant metal fume fever, on one day, and then subjected to such fumes in a corresponding manner on the second day, that no illness developed. This clearly indicates that in the interval between the two exposures he had developed some type of resistance or immunity. This resistance is of short duration, since, in from 48 to 72 hours time after the first exposure, the disease can be reproduced by a second.

An interpretation of these facts is somewhat difficult to arrive at, but it is clear that the effect in the first instance depends upon three significant factors: (1) The con-

centration of metal in the air. (2) Length of time of the exposure. (3) The manner in which one breathes.

The latter is important. The average individual at rest takes in something of the order of magniture of 5 cubic meters of air in the course of an eight hour day. He may breathe in more air during that particular time if he is carrying out heavy manual labor. Actually, the volume of air breathed may be 12 times as much.

It was established experimentally that the individual who exercised moderately over a period of about eight hours tolerated 15 milligrams of zinc oxide fume per cubic meter of air without developing any signs or symptoms of metal fume fever.

Every-Day Terms Confusing

WE ARE so in the habit of speaking of the toxicity of metals that we have often lost our way in our speech and thought. Apparently many of us believe that if a great deal of something is harmful a little must be somewhat harmful. Against that belief is the fact that all of us breathe air which contains particles of a variety of materials which, roughly, are representative of almost anything that occurs in the soil on the surface of the earth. Time after time we find many of the metals referred to as intrinsically poisonous and yet elements such as manganese, copper, iron, lead, selenium, mercury and silver, as well as many others, occur in the food we eat.

Copper is necessary to us. Manganese is necessary in the metabolism of certain forms of life. Lead is absolutely unavoidable. Similarly, we think of acids as poisonous, yet a liter of hydrochloric acid is produced within the body every day.

When one speaks of toxicity in relation to an occupational or other type of exposure, one is concerned not with the exposure, *per se,* but with a degree of exposure. Thus, we come to a point of view which necessitates consideration of safe versus unsafe conditions of exposure. Safety can be defined in terms of concentrations or quantities to which the individual is exposed without risk of injury.

A case in point is our use of maximum allowable concentrations of various gases, vapors or particles in air as an expression of safe occupational conditions. We should be thinking in terms of such limits of safety as will permit a man to work for a lifetime without serious injury. Fifteen milligrams of zinc oxide per cubic meter of the atmosphere appears to be a safe limit in relation to the prevention of metal fume fever. What we mean is that men so exposed in their ordinary working conditions do not develop this disease.

Mechanism of Metal Fume Fever

WHAT is the mechanism of this disease process? It apparently involves the effect of small particles on the lung surface. Since the appearance of this disease is that of an acute infection, the likelihood is suggested that we are dealing with metals in a form in which they act not unlike bacterial agents. So it has been suggested that this disease is produced by the deposition of finely divided and reactive metallic particles upon the extensive alveolar surface of the lung, thereby, inducing injury by denaturing the protein of these cells and causing this denatured protein to be absorbed into the circulation. Evidence in support of these hypotheses has been given by Schmidt-Kehl[5] who reproduced an illness on the part of animals which bore resemblance to metal fume fever. They sprayed blood serum into a cloud of zinc fume. This serum was then collected and injected into animals.

Differential Diagnosis

IN ALL instances a differential diagnosis is necessary as this disease resembles an acute infection at the time of onset and it is difficult to determine whether the individual is coming down with this disease or pneumonia.

In making a diagnosis several factors must be considered.

1. History of exposure: One must determine the time of the onset in relation to the exposure. The time interval between exposure and the development of symptoms is some few hours. In the daytime worker, the symptoms come on in the night of the day on which he was exposed. These matters have to be taken into account. One has to consider the patient's history and interval of non-exposure, whether in relation to a week-end or a vacation.

2. Observation of the course of the disease: Longest course—24 hours. Most

cases are on the way to recovery by the end of 24 hours. The individual is almost certain to go back to work in three days if he has not developed bronchitis or other complicating infections. Generally speaking, these complications do not occur to an important degree. One does not have to wait quite 24 hours to find in this case fever has come on or that chills have subsided. One has to be careful of the many signs, frequently discernible in the chest in the case of metal fume fever, which makes a diagnosis difficult.

This problem is of especial significance following the breathing of cadmium fumes. One may wonder, in this connection, whether the respiratory signs will subside or whether they will progress so as to be indicative of the acute pneumonitis that may occur following exposure to these fumes. Exposure to cadmium fumes is not to be taken lightly, and it is well for the doctor not to accept it too lightly and make decisions on the basis of the belief that the patient is suffering from metal fume fever.

Because differential diagnosis here is difficult many of the cases have very sound justification for being under the care of a physician.

Treatment

THE workers have various remedies for this disease. There is no objection to drinking warm liquids, or warm milk, or keeping warm and as comfortable as possible, and in being quiet. That is about all that the doctor can do. Probably the things that the men do for themselves cannot do much harm.

Prevention

PREVENTION is a matter of control of the exposure. Like most of the exposures to industrial hazards, prevention is the only sound treatment. Prevention is based on a knowledge of the specifications that have to be achieved to provide a safe environment.

We do not have clear information of this type on all metallic substances. From observations on the effects of exposure to hazardous metals such as lead, cadmium and mercury, maximum acceptable concentrations have been proposed for such metals for guidance in the erection of safeguards for the prevention of the occupational diseases caused by them.

These diseases are beginning to disappear in their more serious forms from American industry. Obviously, more attention is being paid to conditions that will prevent occupational poisoning from those metals and as a consequence of these facts, metal fume fever also will largely disappear.

The control is achieved largely by ventilation. The primary function of the physician or medical investigator is to provide the specifications as to what is the safe environment, and to turn those specifications over to the engineers for execution. Masks may be used, under suitable circumstances, for protection against metallic fumes. Local exhausting of air to remove the fumes at the point of their production is the better practice. In general in industrial hygiene, the use of masks is less desirable than the application of ventilation. The more we have to depend upon respirators against protection against metallic fumes, the more incomplete is the control of metal fume fever.

Definite Data on Only One Metal

THE maximum acceptable concentration insofar as zinc fumes are concerned is 15 milligrams per cubic meter of air in the atmosphere for an eight-hour day. It has been observed that three times that concentration is not capable of producing the disease if the period of exposure does not exceed 20 minutes. The limits of safety for exposure to other metallic fumes, with respect to metal fume fever, have not been defined.

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Radiation from the Welding Arc and its Effect on the Eye

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One of the health risks of a welder is that of eye injury to the radiation from the arc. Adequate precautions against this danger are taken in the form of protective filters, the qualities of which have been established by B.S. Specification No. 679, 1947. Not unnaturally, such a specification must err on the side of safety in view of the inadequate availability of data on the radiant energy from the arc and of the magnitude of the risk of eye damage. The following results arose from work undertaken to estimate the intensity as well as the range of the radiation emitted during metallic arc welding, and the absorption of radiation in the eye, in order that safety precautions can be based on more precise knowledge of the risk involved.

The whole range of electro-magnetic radiations is classified according to wavelength in Fig. 1. From the welder's aspect, the ultra-violet, visible and infra-red radiations are significant, although the visible light is the most noticeable. Any dark coloured glass can reduce the intensity of the visible light to a comfortable degree but may have little effect on the two other forms of the radiation, which fail to produce the sensation of vision but which have the properties of being very active biologically.

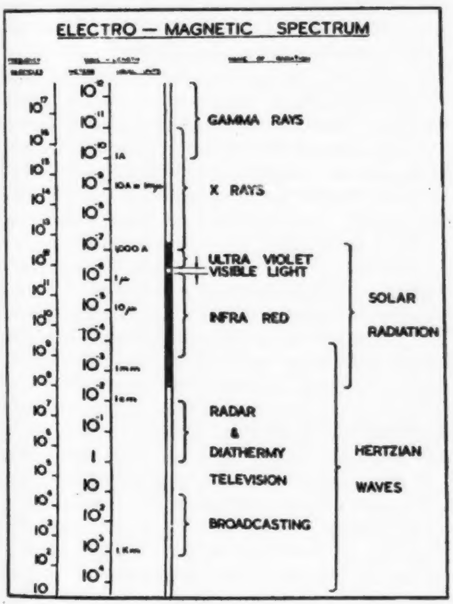

Fig. 1.

Effect of Ultra-Violet on the Eye.—The ultra-violet radiation is known to be dangerous to the human body in wavelengths only slightly smaller than the visible light, which inflame the skin to a depth of only about 1 mm. since they are readily absorbed. Ultra-violet radiation of shorter wavelength might be equally dangerous if it were not so readily absorbed by the atmosphere.

Ultra-violet radiation from the arc is absorbed by the cornea of the eye, the first hard tissue which it meets. In mild doses this produces no immediate effect; like sunburn the discomfort develops after several hours and produces the familiar sensation of sand in the eye, known to welders as "arc eye." A water-cooled high pressure mercury-vapour arc gives ultra-violet radiation as well as visible light, but no infrared since this is absorbed by the cooling water and the injury arising from staring into a searchlight of this type shows that arc-eye is produced by the ultra-violet radiation only.

Effect of Infra-Red on the Eye.—Two types of eye injury have been attributed to infra-red radiations; the more familiar of these is *cataract:*—a change in the tissue of the lens of the eye occasionally observed in elderly glass blowers and furnace workers. This is becoming rather rare as an industrial disease and the authors have not been able to trace any instance definitely attributable to welding. It is customary to predict that, as the number of elderly welders who use inferior types of welding glasses increases with time, some of them will probably suffer from cataract.

The other type of eye injury is due to a burn on the retina where a bright

light, such as the sun, has been focused by the lens of the eye and causes partial blindness which is occasionally permanent.

Units of Radiation

INFRA-RED radiation is perceptible as a sensation of warmth on the skin and quantitative tests have shown that the skin of the face is sensitive enough to detect a rise in temperature of .004 deg. C in 3 seconds. This can be produced[1] by radiation of an intensity of 0.24 milliwatts per square centimeter.

Different physiologists and physicists have used different units for measuring intensity of radiation, but to an engineering reader milliwatts per square centimeter is the most convenient unit since it is related to the ordinary measurement of electrical energy. Actually the effect of radiation in mW/cm^2 is varied considerably by the range of wavelengths received. The figure for heat sensitivity on skin is for the wide range of infra-red obtained from a metal filament lamp filtered so as to remove most of the visible light. The total energy of sunlight is somewhat variable at sea-level for climatic reasons but is of the order of 100 mW/cm^2.

Energy from the Welding Arc

ARC welding now covers a wide range of work and for our measurements we selected the arc from a 4 gauge coated electrode using 280 amps., so as to be above the average range but not outside that used for routine work in heavy engineering. The total energy input to an arc of this type is about 7.0 kW. and this figure was used as a basis for calculating the maximum energy which can be radiated, as described below. The whole range of welding currents used corresponds to an energy range from about one-tenth to about three times this figure, but it is to be expected that the distribution of the radiation over various wavelengths will not change very much in this range. Gas welding operations produce quite a different mixture of radiations and are not discussed in this paper.

The task of assessing the danger from a welding arc can be divided into two parts; (1) determination of total energy radiated, and (2) allocation of the energy between different wavelengths some of which are dangerous and others innocuous. Assessment of the total radiation is usually done by guessing since it is very difficult to include all the factors on which to base a scientific estimate. An estimate for an arc using 7.0 kW. as described below, results in a figure of 3 kW. for the energy radiated. An attempt to verify the estimates by direct measurements, using a vacuum thermopile, was made in our laboratory.

Observations of the Arc

OBSERVATIONS were made on a welding arc of the type described above with the vacuum thermopile at a distance such that the output of the thermopile gave a suitable galvanometer deflection; and assuming the inverse square law the deflection was recalculated to a distance of 31.6 cm., which is the least distance at which a welder is likely to view an arc through a screen.

It was found that the total energy received by the thermopile varies considerably with the angle at which the arc is viewed; and normal conditions were approached by viewing the arc at an angle of 45 deg. in a plane at right angles to that of the electrode; this gives a viewing angle similar to that of the welder.

The measurements will be given in detail below but one can estimate roughly from the radiations received at 45 deg. what the total radiation from the arc and pool would be, on the assumption that it is a point source radiating uniformly over a hemisphere. This gives a figure of 1.7 kW., i.e. 24 per cent of the energy input of the arc. The actual intensity of radiation received by the thermopile corresponded to 135 $mW/cm.^2$ at 31.6 cm. range, or 85 $mW/cm.^2$ at 40 cm. range.

As one is not accustomed to estimate energy in milliwatts per $cm.^2$ at the eye, figures have been collected at various places for the total energy in sunlight in the same units and these range from 10 to 100 $mW/cm.^2$ according to the time of year.

Distribution of Radiant Energy

A radiating body, such as the metal filament of a lamp or a piece of red hot coal, emits light and heat of a mixture of wavelengths which can be represented by a curve of the type shown in Fig. 2. The shape of the curve can be calculated on the assumption that the radiation is that of an ideal "black body" and is summarized by

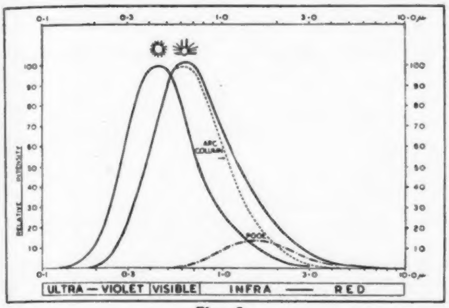

Fig. 2.

Energy distribution in sunlight and the welding arc

two numbers; a wavelength corresponding to the peak of the energy curve and a brightness figure corresponding to the energy radiated per sq. cm. of the hot surface. The latter is represented by the area under the whole of the curve and the height of the curve at any point represents the relative intensity of radiation with that wavelength.

In order to calculate the distribution of radiation from a welding arc we have added together the radiation from a black body at 4650 deg.K representing the arc itself and the radiation from a pool of molten metal at 1930 deg.K representing the crater. The temperature assumed for the arc gives a peak of the arc emission at ·625μ; this is a lower temperature than some Canadian estimates[2] of arc temperature. By inspection of the welding arc and after making allowances for the depth of cup at the electrode tip, we have estimated it to be a cylinder about 10 mm. long and 3 mm. in diameter with an area of 1 cm^2; this determines the total energy radiated and hence the height of the peak in Fig. 2. The pool of molten metal is estimated to be about 12 mm. wide x 20 mm. long with a surface area of 1.8 cm.^{2} and a temperature about 200 deg. C above the melding point of steel. The peak of the radiation curve from this source is at 1.5μ and its height is 14 per cent of that for the arc curve. The total energy radiated by a black body is given by the formula—

$5.67 \times T^4 \times$ the area $\times 10^{-12}$ Watts

Hence we get from the:—

	Area	*Total Watts*
Arc column	1 cm^2	2,650
Metal pool	1.8 cm^2	356
Total energy		3,006

The percentage energy in each of four wavelength ranges was calculated as a fraction of the total and the distribution of energy between the wavelength ranges given in Table 1.

TABLE I.
ENERGY DISTRIBUTION IN THE RADIATION FROM A WELDING ARC.

Wave Band		Arc + pool		% reaching retina of eye
Ultra-violet	0.2 — 0.4μ	5		0.24
Visible	0.4 — 0.75μ	26		16
Infra-red	0.75 — 1.3μ	31	69	12
	beyond 1.3μ	38		0

The figure for wavelengths beyond 1.3 is an approximate one based on assuming linear approach of the graph to zero at 10μ

Radiation Absorbed in the Eye

THE Grotthus-Draper law states that radiant energy must be absorbed in order to produce a reaction; therefore, only the rays absorbed by the lens of the eye and its adjacent tissues can play a part in causing an injury; the adjacent tissues are included because, if they are warmed by the energy they absorb, they cease to be able to play their part in cooling the lens. Unfortunately, opinions about the absorption of radiation by the tissues of the eye are not unanimous; it appears that beyond 1.3μ the tissues are completely opaque, but between 0.75 and 1.3μ there is a region where a fraction of the energy is absorbed.

Since 31 per cent of the energy in the arc appears in this wavelength range, a calculation has been made of the energy transmitted to the retina, using a table for the transmission of the ocular media provided by Dr. R. H. Peckham, of Temple University, Philadelphia. This gives a set of figures for each of the four wavebands measuring the percentage of the original energy radiated by the arc which can reach the retina, and these figures have been put in the final column of Table 1. The energy absorbed in the tissues, which alone can produce heat, is then obtained by subtracting the 12 per cent which reaches the retina from the 69 per cent infra-red energy; leaving a final figure of 57 per cent.

Test on Bullock's Eye

AS A human eye was not available measurements were made with a bullock's eye partially dissected and enclosed between

two fused quartz plates 20 mm. apart. The eye from a freshly killed bullock was procured and opened; the cornea, lens and vitreous humour were transferred to the quartz cell after removing the iris so as to leave a clear circle about ¾ in. in diameter through which observation could be taken. The cell was completely filled with the liquid from the eye so as to minimize any refractive effect and measurements were made before turbidity set in due to incipient decomposition of the tissues.

Observations were made of the energy transmitted by the cell from a welding arc, taking about 280 amps. as specified above, and these were supplemented by measurements on the cell filled with water and the cell filled with 10 per cent ferrous ammonium sulphate. It was found that the absorption by the bullock's eye was intermediate between that of water and ferrous ammonium sulphate solution and, for subsequent measurements of sunlight, only the absorption by water and ferrous ammonium sulphate was measured since the eye had become turbid. The results are summarized in Table II in which they are expressed in mW/cm.^{2} for comparison with those quoted above. Of the total radiation transmitted by the quartz plates about a quarter was transmitted through the eye.

Measurements on Sunlight

SIMILAR observations on sunlight indicate that of the radiation transmitted by the quartz plates, about half is transmitted through the fluids of the eye. This confirms that about three quarters of the radiation from an unfiltered welding arc is liable to be absorbed in the tissues of the eye; or for sunlight more nearly a half. The quartz plates forming the cell absorbed a considerable fraction of the radiations with wave lengths greater than 5μ, but this is the most transparent material available from which a cell can be made.

Comparison of Welding Arc and Sunlight

THE measurements quoted in Table II and other measurements quoted above confirm that the total energy which can be received from the sun by an observer at the earth's surface is approximately equal to that of a welding arc of the type described at a distance of about 32 cm. and in both cases the fraction of the radiation which can be absorbed so as to cause a chronic injury in the eye is roughly similar. It is suggested that a reasonable standard of protection from infra-red in the welding arc would be given by a filter whose absorption is similar to that of the human eyelid.

TABLE II.
THERMOPILE READINGS OF ENERGY THROUGH 20 MM. CELL.

Observed through	Welding Arc		Sunlight	
	mW/cm^2	%	mW/cm^2	%
No cell	135	—	148	—
Cell empty	95	70	93	67
Cell + water	38	28	68	46
Cell + $Fe(NH_4)_2(SO_4)_2$	18	13	36	24
Cell + eye	22	16	—	(abt) 33

Radiation Reaching the Retina

A RETINAL burn can only be produced by the infra-red radiation of wavelength between .75 and 1.3μ, since beyond that wavelength the other tissues of the eye are completely opaque. Visible radiation might also contribute its energy to cause this type of injury and it is hard to disprove this, since until recently it has been difficult to obtain filters which separate the visible radiation from the near infra-red.

Tests on Shade 8 Filter

AS A check on the danger to the eye which might be thought to arise from the fact that this type of filter does not comply with the B.S. specification, a shade 8 glass was obtained with a visible density of 3.0 and a density to total heat of 1.2. A glass of this shade is considered by most welders too light for any type of arc welding. The infra-red absorption spectrum of this goggle glass was measured and is plotted against wavelength in Fig. 3. The quantity of energy transmitted in the near infra-red region by this filter was worked out by taking the figures for the relative energy in the welding arc at various wavelengths from Fig. 2. (as percentages of the total energy) and multiplying each by the transmission of the filter at that wavelength, using the fraction of light transmitted instead of the density plotted in Fig. 3.

The resultant curve has also been plotted in Fig. 3 and gives the energy reaching the eye at each wavelength as a percentage of the total energy radiated by the arc. The area under this curve has been calculated by adding the products and in the wave-

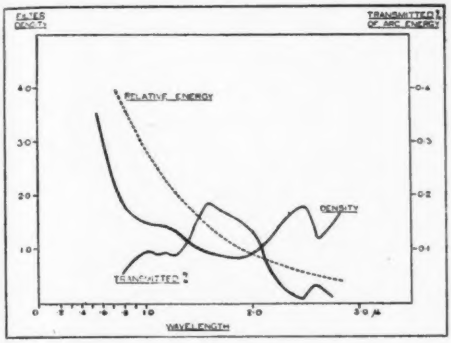

Fig. 3.
Infra-Red absorption of a welding glass

length range of 0.75 to 1.3μ, known to be dangerous to the retina, the transmitted energy is 0.92 per cent. If this is augmented by an estimated figure of 0.65 per cent for the energy transmitted in the visible spectrum, we get a total of 1.7 per cent, which for a welding arc observed at a distance of 31.6 cm. corresponds in intensity to 2.3 mW/cm.^{2} at the eye. The total area under the curve can be estimated as about 5 per cent of the arc energy or 6.8 mW/cm^2.

In order to obtain direct confirmation of this estimate, measurements of total energy were made through this goggle glass set about 30 cm. from the welding arc, observed at an angle of 45 deg. as before. The total radiation reaching the vacuum thermopile was reduced to about half the value previously observed, but this is partly due to the difficulty of striking an arc at a specified point, partly to the cover glass and partly to the fact that the inverse square law does not hold strictly for a source as large as the pool of welding arc. The figures for total radiation in mW/cm^2 are:

	mW/cm^2
Through cover glass only	77
Through cover glass + filter	4.6

This observed figure of 4.6 mW/cm^2 for the filter plus the cover glass affords a reasonably good confirmation of the calculated figure of 6.8 mW/cm.^{2} obtained above for the filter without a cover glass.

Observation of Welding Arc Through a Filter

As a further check on the safety of this type of welding glass, one of the authors stared at an arc from a 4 gauge electrode carrying 280 amps. through the Shade 8 filter in this position for exactly 2 minutes, using one eye only. The arc was unpleasantly bright and produced an "after image" that persisted for several minutes. Two hours later the vision of each eye was tested by a specialist who reported that there was no sign of any visual deficiency. With filters normally used, therefore, the factor of safety against eye injury due to infra-red is considerable.

The ratio of the total-heat density of this filter (1.2) to the prescribed minimum density of 3.0 is 1/630, since the density is the logarithm of the reciprocal of the fraction of light transmitted.

Conclusions

Measurements have been made of the radiation from the welding arc which show that the total radiation which can reach the welder is of about the same intensity at his eye as the radiation from direct sunlight. As regards the risk of cataract from radiation absorbed in the cornea and lens of the eye, the transmission factor of a filter for infra-red radiation would be safe if it is of the same order as the reflection factor of our average surroundings for the corresponding wavelengths. With respect to retinal burns from radiation transmitted through the eye to the retina, direct exposure of an observer's eye to a welding arc has established an intensity level which is safe. This confirms that the current B.S. Specification allows a factor of safety of the order of 500.

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References

1. Hardy & Oppell, *Physics*, 1936, 7, 466-479.
2. Canad. Journ. Research, 1947, 25, 42-48.

American Industrial Hygiene Association

—News of the Local Sections—

New England Section

A FULL DAY meeting of the New England Section is to be held in Hartford, Connecticut on November 5, 1948. The program will be as follows:

Chairman: Albert S. Gray, M.D., Director, Connecticut Bureau of Industrial Hygiene.

Preliminary Report on Comparison of Instruments for Sampling Lead Dust in Air: Warren Hough, Travelers Insurance Company, Hartford.

The Lead Hazard in Sand Buffing Operations: Robert M. Elrick, Connecticut Bureau of Industrial Hygiene.

Improved Lead Controls in Storage Battery Plants: Fred W. Sehl, Aetna Casualty & Surety Company, Hartford.

New Insecticides, Exterminators and Fumigants: Harold A. Thiemann, Hartford Accident & Indemnity Company, Hartford.

The Engineering Control of Industrial Beryllium Exposures: Louis J. Prouex, Connecticut Bureau of Industrial Hygiene.

Ultrasonic Sickness: Crit Pharris, M.D., Assistant Medical Director, United Aircraft Corporation, East Hartford.

The Control of Health Hazards in Hard Rock Tunnelling Operations: Alex E. Goss, Connecticut Bureau of Industrial Hygiene.

An Accurate Film Monitoring Technique: An adjuvant in Radiation Protection: Roy M. Seideman, M.D., Connecticut Bureau of Industrial Hygiene.

Remarks on Nuclear Operations: R. C. Stratton, Travelers Insurance Company, Hartford.

The Engineering Control of Dust Producing Operations in Monumental Granite Establishments: George F. Nevers, Connecticut Bureau of Industrial Hygiene.

The Methanol Exposure in the Operation of Duplicating Equipment: Grant H. Vance, Connecticut Bureau of Industrial Hygiene.

Chicago Section

THE SEPTEMBER meeting was addressed by Mr. Harry Gragg, Engineer, American Air Filter Company on the subject "Some Practical Aspects of Industrial Dust Control." Mr. Gragg discussed unit dust collectors—types, efficiency, applications, acceptability and costs—and maintenance of dust collection systems. Slides showing actual installations were presented.

The October meeting is to be held during the week of the National Safety Congress and is to be addressed by Mr. L. V. Taylor, Supervisor, Industrial Health Division, American Can Company, New York City, on the subject "Trends in Industrial Medicine, Hygiene and Safety Problems."

The November meeting is to be addressed by J. Garrott Allen, M.D., Assistant Professor of Surgery, University of Chicago, on the subject "Health Problems of Radioisotopes—Present and Future."

Metropolitan New York Section

A SYMPOSIUM on the present status of effect of beryllium on health was presented at the September 29 meeting.

Clinical aspects were discussed by Irving Tabershaw, M.D., Regional Medical Director, Liberty Mutual Insurance Company; Epidemology, by Cyril Dustan, M.D., Columbia University School of Public Health; Engineering Aspects, by Mr. Merril Eisenbud, Chief, Health and Safety Branch, U.S. Atomic Energy Commission, Office of New York Directed Operations.

"Industrial Wastes" will be the subject presented by Mr. Charles C. Spencer, Assistant Professor of Sanitary Science, Columbia University, School of Public Health at the October 27 meeting.

Pittsburgh Section

THE FALL meeting to be held on October 5, 1948 will be addressed by John F. Haines of the Industrial Hygiene Foundation of America on the subject "Radiant Heat Exposures and Their Control."

New Jersey and Philadelphia Sections

THESE SECTIONS will combine with the Metropolitan New York Section for their Second Annual Joint Meeting to be held in New York City on Friday, December 10.

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